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PRIMARY AND SECONDARY CELLS.

(PREVIOUSLY RGP 081)

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★ AMENDED 1962

1. INTRODUCTION.

1.1 An electric cell is a device which changes chemical energy into electric energy; electricity is not stored in these cells. There are two main types -

- (i) Primary cells,
- (ii) Secondary (or Accumulator) cells.

When two or more cells are connected together, the arrangement is called a battery.

1.2 In Primary Cells, the active materials of the cell are used or exhausted during the process of providing electric energy. When the elements of the cells are used, the cell has finished its useful life. We can replace these elements with new ones, but the old elements cannot be restored to their original condition.

Primary cells can be subdivided into wet cells and dry cells. Many different types of wet primary cells have been used but these are now replaced by the dry cell for use in the Department.

Dry cells and batteries are used mainly to supply a relatively low current for intermittent service in telecom equipment, for example, in magneto telephones, in portable radio equipment, and in some testing instruments.

1.3 In Secondary Cells (generally called Accumulators), the chemical action which takes place when the cell supplies current, is reversible; we can restore the elements of the cell to their original state by charging.

Accumulator cells and batteries are used at many telecom stations where a fairly continuous large current is required, for example, as the central battery for the operation of a telephone exchange.

1.4 This paper gives a general understanding of the construction and operation of dry cells and accumulators, and shows how Stray Current Electrolysis (a chemical action similar to that which occurs in the charging of an accumulator) can cause deterioration in the lead sheath of a telephone cable.

2. PRIMARY CELLS.

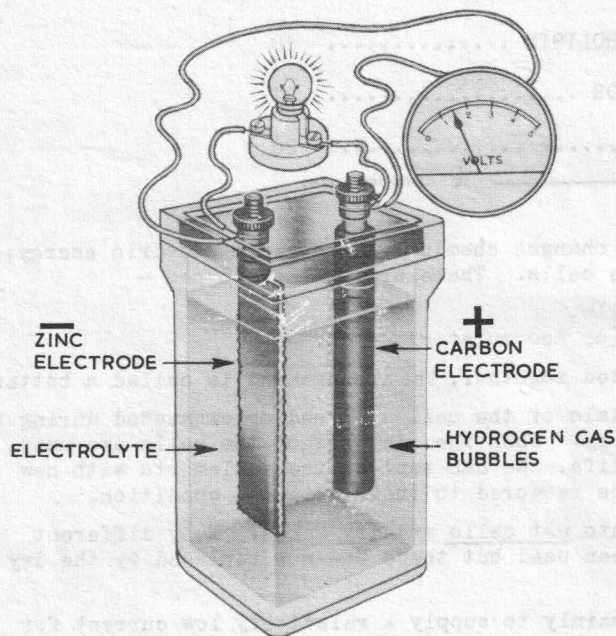
2.1 Simple Voltaic Cells. A steady flow of electricity was first produced in 1799 by chemical action in the Voltaic cell, so called from its originator, Volta, an Italian professor of physics.

In the simple primary cell of this type, a source of e.m.f. is obtained by placing two dissimilar conductors in a chemical solution. The value of the e.m.f. is dependent on the type of dissimilar conductors and nature of the solution.

The following list shows approximate values of e.m.f. from various combinations of conductors and solutions -

Conductors	Solutions	Approx e.m.f.	Conductors	Solutions	Approx e.m.f.
Copper and Zinc.	Sulphuric Acid.	0.8 volt	Copper and Carbon.	Sulphuric Acid.	0.25 volt
Brass and Zinc.	Sulphuric Acid.	0.2 volt	Carbon and Zinc.	Sulphuric Acid.	1.5 volt

Alternatively, solutions of common salt used in each case, produce e.m.f.'s of much lower values than those quoted. The pieces of carbon, copper, zinc, etc., are called plates or electrodes and the solution is termed the electrolyte.



In commonly used primary cells, the electrodes are carbon and zinc and the electrolyte is salammoniac, (ammonium chloride) (Fig. 1).

In this cell, the negative terminal is connected to the zinc electrode, and is the terminal from which electrons from the cell pass to the external circuit or load. The positive terminal connects to the carbon electrode.

2.2 Operation of Cell. While the electrodes of the simple cell shown in Fig. 1 are disconnected externally no current flows, but when the circuit is closed, for example, by connecting a lamp to the terminals a discharge current will flow from the cell through the lamp.

The chemical changes which result in current flow produce a visible change in the components within the cell.

They are -

- (i) Some of the zinc electrode is eaten away.
- (ii) Hydrogen bubbles form around the carbon electrode.

FIG. 1. SIMPLE PRIMARY CELL.

2.3 Chemical Action. The electrolyte of the voltaic cell contains a large number of negatively and positively charged ions which are able to move freely. When the zinc and carbon electrodes are immersed in the electrolyte, a chemical action takes place, and the electrodes each take up a difference of potential to the electrolyte, and a potential difference to each other of about 1.5 volts, the zinc electrode being a negative polarity with respect to the carbon electrode.

When the external circuit is closed electrons will flow through the load as a result of the P.D. between the electrodes.

The chemical action within the cell maintains the P.D. between the electrodes and may be briefly summarised as follows -

In the electrolyte which consists of ammonium chloride (NH_4Cl), there are present positively charged ammonium ions (NH_4^+), and negatively charged chlorine ions (Cl^-). When current flows, the chemical action results in the eating away of the zinc plate, as positively charged zinc ions are removed to unite with negative chlorine ions forming zinc-chloride (ZnCl_2) in the electrolyte. The electrons from the zinc ions remain on the zinc plate maintaining its negative potential.

The positively charged ammonium ions are urged towards the carbon electrode where they are neutralised by electrons from the carbon, maintaining it at a positive potential.

The chemical change which takes place results in the formation of ammonia gas which is liberated, and hydrogen gas which accumulates around the carbon rod in the form of a layer of bubbles.

Whilst the cell is delivering current to the external circuit, there is a steady movement of negative ions through the electrolyte to the zinc electrode, and a steady movement of positive ions to the carbon electrode in the opposite direction.

This is termed a convection current which occurs in electrolytes; it is distinct from the conduction current which occurs in conductors.

- 2.4 Polarisation. As the cell delivers current to an external load and the chemical action continues, the layer of hydrogen around the positive carbon electrode increases. This has the effect of reducing both voltage and current.

The hydrogen tends to set up an electromotive force in a direction opposite to that of the cell, decreasing the effective e.m.f. of the cell. It also reduces the conducting area of the plate and so increases the Internal Resistance of the cell.

When a cell which has become polarised is allowed to stand on open circuit, the hydrogen gradually disappears, and the terminal voltage of the cell is eventually restored.

- 2.5 Leclanche Cell (Fig. 2). This type of cell uses the same electrodes and electrolyte as shown in Fig. 1, but eliminates polarisation whilst the cell is working, by using a depolariser to chemically absorb the hydrogen gas, and prevent it from affecting the operation of the cell.

The depolariser in the Leclanche cell is manganese dioxide (MnO_2). In its essential action the manganese dioxide gives up oxygen which combines with the hydrogen to form water.

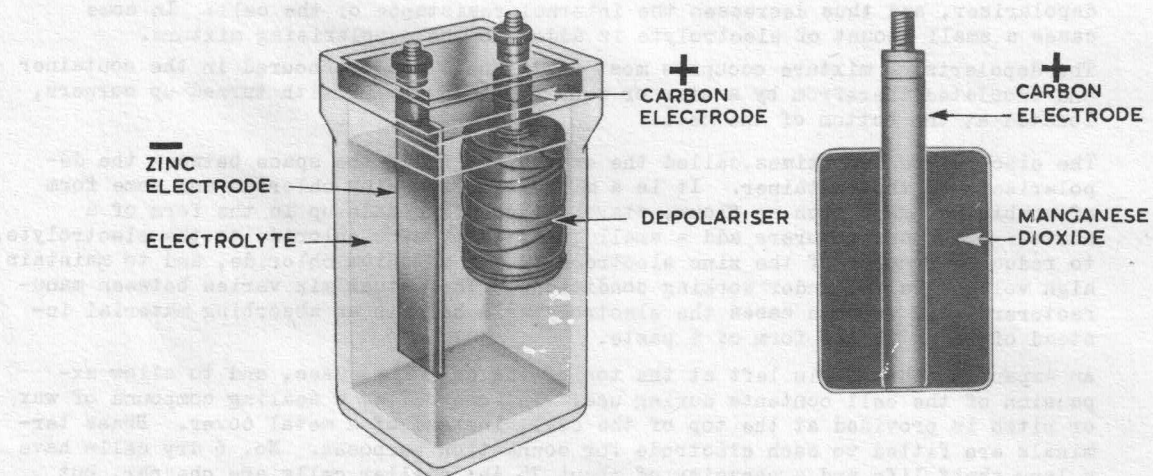


FIG. 2. COMPONENTS OF A LECLANCHE CELL.

- 2.6 Dry Cell. This cell contains the same components, and has the same chemical action as the Leclanche cell, but the salammoniac electrolyte is in the form of a thick damp paste, which prevents spilling, and makes the cell more portable.

Actually the cell is not dry, for the electrolyte must be moist or the cell would not work; in practice, a cell often fails because the electrolyte is dry.

Dry cells are made in many different sizes, but the No. 6 dry cell (Fig. 3) is the one most commonly used in the P.M.G.'s Department, principally in magneto telephones. The general description and operation of this cell applies also to other types of dry cell except for minor details of mechanical assembly.

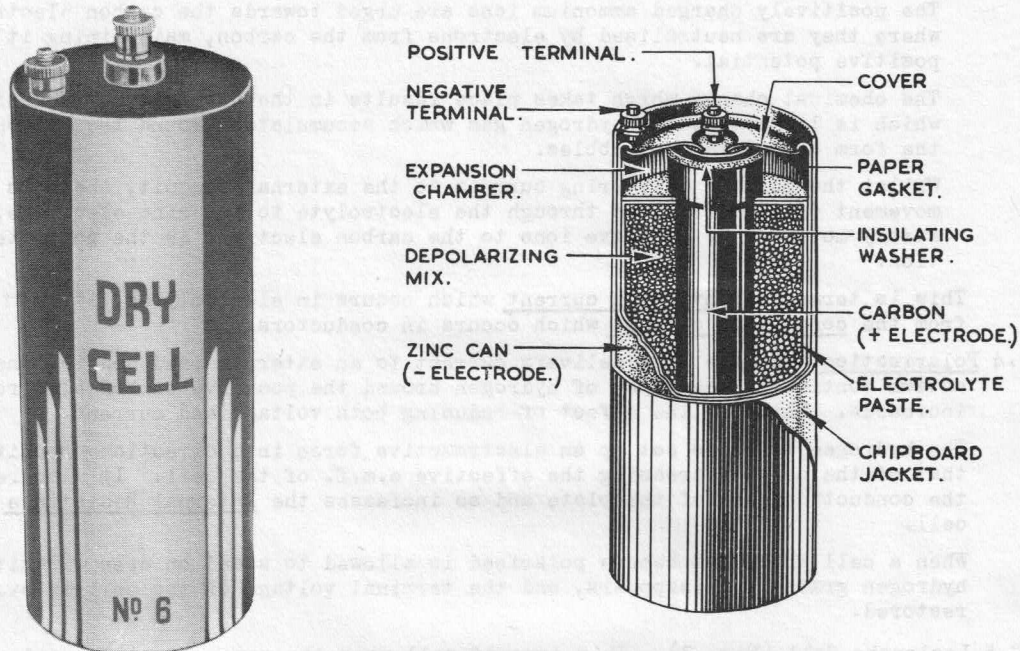


FIG. 3. NO. 6 DRY CELL - SECTIONAL VIEW.

A cylindrical zinc container, which is also the negative electrode, is enclosed in a cardboard outer wrapping to avoid damage and to insulate the electrode from adjacent cells.

The positive electrode is a carbon rod surrounded by a depolarising mixture of manganese dioxide and ground carbon. The latter increases the conductivity of the depolariser, and thus decreases the internal resistance of the cell. In some cases a small amount of electrolyte is added to the depolarising mixture.

The depolarising mixture occupies most of the cell and is secured in the container and insulated therefrom by a star or square shaped washer with turned-up corners, located at the bottom of the cell.

The electrolyte (sometimes called the excitant), fills the space between the depolariser and the container. It is a mixture of ammonium chloride and some form of combining agent such as flour, starch or gelatine made up in the form of a paste. Some manufacturers add a small quantity of zinc chloride to the electrolyte, to reduce corrosion of the zinc electrode by the ammonium chloride, and to maintain high voltage values under working conditions. The actual mix varies between manufacturers, and in some cases the electrolyte is held in an absorbing material instead of being in the form of a paste.

An expansion chamber is left at the top of the cell for gases, and to allow expansion of the cell contents during use. In some cells, a sealing compound of wax or pitch is provided at the top of the cell, instead of a metal cover. Brass terminals are fitted to each electrode for connection purposes. No. 6 dry cells have a long shelf life and a capacity of about 75 Ah; smaller cells are cheaper, but have a much shorter shelf life and lower capacity.

- 2.7 Local Action - Commercial zinc which is used for the negative pole of most dry cells, contains many impurities such as iron, lead and tin, etc. These impurities together with the pure zinc and the electrolyte, form tiny voltaic cells with

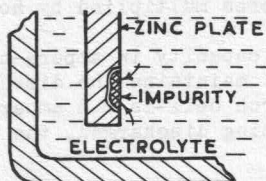


FIG. 4. LOCAL ACTION.

closed electrical circuits, and thus the zinc is eaten away, although the cell may not be delivering current to an external circuit (Fig. 4). To prevent local action, the zinc is subjected to a treatment called "amalgamation". Mercury is added to the zinc before casting or is rubbed over its surface. Either of these processes forms a mercury-zinc amalgam film on the surface of the zinc. When the cell is working, the electrolyte is able to act on the zinc in the film, and the plate acts as a normal zinc plate. The im-

purities which do not dissolve in the mercury are covered with the film, and local action cannot occur.

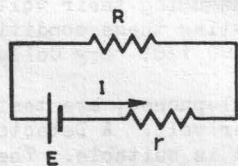
- 2.8 The Internal Resistance of a Cell, is its total resistance to the flow of current. It is due to the electrodes, electrolyte, and depolariser, which are not perfect conductors. The larger the electrodes and the closer they are together, the smaller the internal resistance.

The average value of internal resistance for a dry cell is approximately 0.5 ohm. This figure increases with age, rising slowly at first, but later as the cell is used, rising rapidly to large values. This is due to -

- (i) The effects of polarisation. With age the depolariser becomes ineffective, and hydrogen forms a high resistance layer around the positive electrode.
- (ii) Chemical action. Secondary chemical effects take place within the cell, forming compounds which offer high resistance to the current.

The e.m.f. or open circuit voltage of a cell, is measured in practice by the voltage reading of a high resistance meter connected to the terminals, when the cell is open circuit.

The terminal voltage of the cell measured during discharge is always less than the e.m.f., as a proportion of the voltage must be used in forcing current through the internal resistance of the cell. Under load therefore, the voltage applied across the load resistance, (terminal voltage or P.D.), will be equal in value to the e.m.f. minus the voltage drop across the internal resistance. Fig. 5 shows the equivalent circuit of a dry cell under load.



E = e.m.f. of cell

R = load resistance

I = circuit current

r = internal resistance of cell

FIG. 5. EQUIVALENT CIRCUIT SHOWING INTERNAL RESISTANCE.

In problems involving cells (or batteries), the e.m.f. figures quoted always refer to the open circuit voltage, and when the internal resistance value is given, it must be treated as an additional series resistance. However, in examples where the cell (or battery) is providing a small current through a high resistance load, the internal resistance of the cell is of such a small ratio to the overall resistance, that it is often neglected in calculations.

- 2.9 Dry Cell Batteries. A single dry cell has a normal voltage of 1.5 volts. For higher voltages a dry cell battery is used which is constructed of a number of single cells connected in series. The purpose for which the battery is designed determines the size and number of the individual cells, but as dry batteries are not designed to deliver large currents, batteries providing high voltages and low currents can be made in fairly compact sizes.

- 2.10 The capacity of any cell (or battery) is the quantity of electricity it can supply before becoming discharged. It depends on the efficiency of the chemical components and the surface area of the electrodes, and is usually expressed in terms of ampere-hours (abbreviated to Ah), which means amperes multiplied by hours.

When a cell is discharged at a constant current, the capacity in ampere-hours is the product of the current and the time that the cell maintains the discharge. For example, when the average discharge rate of a torch cell is 0.3 ampere, and the cell gives this current for 10 hours before becoming discharged, the capacity is 3 Ah.

As the current does not usually stay constant but falls during a discharge, the average current is calculated from readings taken at periods during the discharge.

The larger the size, the greater the capacity of a cell.

- 2.11 The desirable qualities in a primary cell are -

- (i) high and constant terminal voltage;
- (ii) no polarisation;
- (iii) no local action;
- (iv) low internal resistance;
- (v) free from objectionable fumes;
- (vi) long shelf life;
- (vii) high capacity.

There is no cell with all these qualifications, but the dry cell satisfies most requirements, and is the standard primary cell used to operate telecom equipment.

- 2.12 Shelf Life is a measure of the lasting quality of a dry cell or battery when not in use. Its deterioration over a period of time is due to a number of factors, some of which are temperature, materials used in construction, and method of sealing.

Cells and batteries should always be stored upright, in a cool well ventilated location when not in use.

- 2.13 Testing Dry Cells and Batteries. In general, unless specific tests are laid down by the manufacturer, dry cells and batteries are tested by connecting them in the circuit in which they normally work, and measuring their voltage under actual working conditions (or circumstances simulating these conditions). This method of testing is in E.I. POWER PLANT Batteries C 1201 "Dry Cells".

For example, No. 6 cells used in magneto telephones, are tested with a voltmeter having a resistance of at least 100 ohms per volt. A Detector No. 4 on the 5 volt range has a resistance of 500 ohms and is suitable. The voltage of each cell is measured after supplying current for one minute to its normal load circuit, or a simulated circuit of equivalent resistance. Any cell which shows a reading of 1 volt or less should be discarded.

Similarly, a battery block used to supply current, is discarded when its voltage falls to two-thirds of its nominal rated value, after supplying current for one minute. For cells other than the No. 6 cell, a voltmeter with a resistance of at least 1000 ohms per volt is used.

In some types of telecom equipment, cells and batteries are used mainly to supply a P.D. instead of a current, for example, as bias batteries for thermionic valves. The usual lower limit of voltage for bias batteries is 1.4 volts per cell, and the cell or battery should be discarded when the voltage, measured on a voltmeter of at least 1000 ohms per volt, is 1.4 volts (or less) per cell.

3. GROUPING OF DRY CELLS.

3.1 In telecom circuits, cells can be connected either in series or in parallel, to increase the e.m.f. or current in the circuit. As a cell is both a source of e.m.f. and a resistance, the method of connection of a number of cells comprising a battery, will affect both the e.m.f. and resistance of the battery.

3.2 To connect cells in series, join the positive terminal of one cell to the negative terminal of the next cell, and so on. Fig. 6 shows a battery of four cells connected in series.

If the e.m.f. of each cell is 1.5 volts, and the internal resistance of each is 0.3 ohm, then the battery as a whole has an e.m.f. of 6 volts, and an internal resistance of 1.2 ohms.

Cells (and batteries) of different e.m.f.'s can be connected in series, for example, 2 volt cells can be connected in series with 1.5 volt cells.

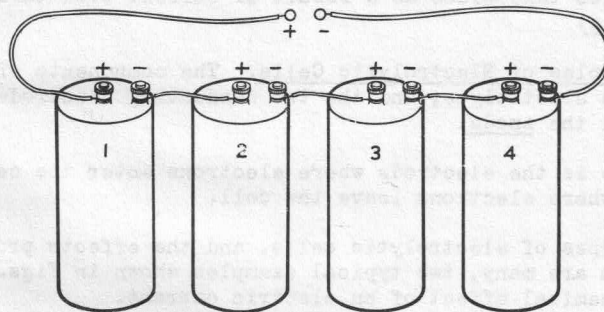


FIG. 6. HOW TO CONNECT CELLS IN SERIES.

3.3 To connect cells in parallel, join all the positive terminals together to a single wire, and all the negative terminals to another wire. Fig. 7 shows a battery of four cells (each with the same e.m.f.) connected in parallel. This gives the equivalent of one larger cell. The e.m.f. of the battery is still the same as the e.m.f. of one cell, but the internal resistance is reduced, and is calculated in the same way as for separate resistances in parallel. Under working conditions each cell will supply one quarter of the total current.

Cells (and batteries) should not be connected in parallel unless their e.m.f.'s are all the same, as those with higher e.m.f.'s discharge through those with lower e.m.f.'s.

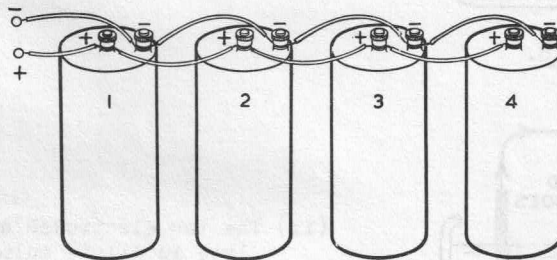


FIG. 7. HOW TO CONNECT CELLS IN PARALLEL.

3.4 Present day telecom practice does not require dry cells to be connected as shown in the form of a battery, except as an emergency measure. In this case it should be remembered that cells connected in series will provide the necessary e.m.f., but to supply the circuit current demands and keep the internal resistance within reasonable bounds, banks of cells may have to be connected in parallel.

4. CHEMICAL EFFECT OF AN ELECTRIC CURRENT.

- 4.1 Electrolytic Cell. In previous papers, the Magnetic and Heating effects of an electric current have been discussed, and it has been shown that in the voltaic cell, two dissimilar metals in an electrolyte can provide a source of e.m.f. for current flow in an externally connected circuit.

Now let us examine the effects produced, when current from an external source is passed through a cell containing two electrodes and an electrolyte.

When a source of e.m.f. is connected to such a cell, current will flow through the cell, and chemical changes will occur in the components of the cell. Experiments show that the nature of the chemical changes which take place, depend on the material used for electrodes, and the type of solution used as the electrolyte.

Such a cell is usually referred to as an electrolytic cell, and the chemical changes which take place as a result of current flow through the cell, are termed Electrolysis.

- 4.2 Typical examples of Electrolytic Cells. The components of the cell are the container, the electrolyte, and the two conducting electrodes, which are termed the cathode and the anode.

The cathode is the electrode where electrons enter the cell. The anode is the electrode where electrons leave the cell.

Although types of electrolytic cells, and the effects produced by electrolysis within them are many, two typical examples shown in Figs. 8 and 9 will serve to show the chemical effect of an electric current.

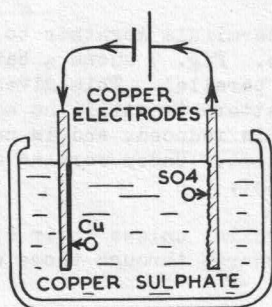


FIG. 8.

- (i) The two electrodes are copper (Cu) and the electrolyte is copper sulphate (CuSO_4). By electrolysis, copper is deposited on the cathode, the anode is eaten away, and the strength of the electrolyte remains unchanged.

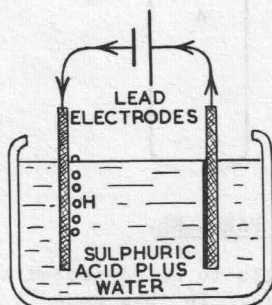


FIG. 9.

- (ii) The two electrodes are lead (Pb), and the electrolyte is dilute sulphuric acid ($\text{H}_2\text{O} + \text{H}_2\text{SO}_4$). By electrolysis, the anode is coated with lead peroxide, hydrogen gas is given off at the cathode, and the strength of the electrolyte is increased, by the diminishing water content.

4.3 Chemical Action. The chemical action of the electrolytic cell shown in Fig. 8 will be discussed briefly, but in general the principle is the same for each cell, although the chemical action differs.

When copper sulphate (CuSO_4) is mixed with water, the molecules split up into positively charged copper ions (Cu), and negatively charged sulphate ions (SO_4) (Fig. 10).

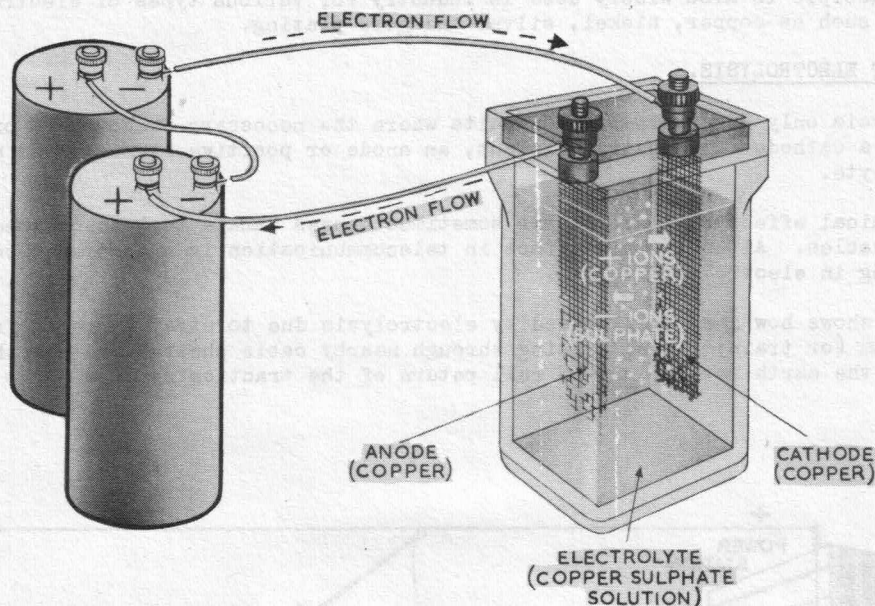


FIG. 10. CHEMICAL ACTION IN AN ELECTROLYTIC CELL.

When the electrodes are connected to a battery, the cathode takes up a negative potential with respect to the anode, and the ions within the electrolyte are in an electric field. The positive ions are attracted to the cathode and the negative ions are attracted to the anode; this constitutes a convection current within the electrolyte.

The positive copper ions on reaching the cathode are neutralised by electrons from the cathode, and are deposited as a layer of pure copper on that electrode.

When the negative sulphate ions reach the anode they are neutralised, and a chemical change takes place resulting in copper being eaten from the anode, and uniting with the sulphate to form copper sulphate in the electrolyte.

Thus, by electrolysis, there is a transfer of copper atoms from anode to cathode through the electrolyte, which will continue until the anode is dissolved.

4.4 The amount of copper deposited is proportional to the quantity of electricity passed through the cell.

A current of one ampere for four hours will deposit the same amount of copper as a current of two amperes for two hours. The type of cell shown in Fig. 10 is used as a current measuring device, to define the ampere in terms of its chemical effect. In this relation the ampere is defined as follows:-

The ampere is that unvarying current, which when passed through a solution of silver nitrate in water, deposits silver on the cathode at the rate of 0.001118 grams per second.

- 4.5 Applications of Electrolysis. The chemical effect of an electric current has an important application in telecommunication, with respect to some types of electric cells and batteries. This will be explained in Section 6 relating to Secondary Cells.

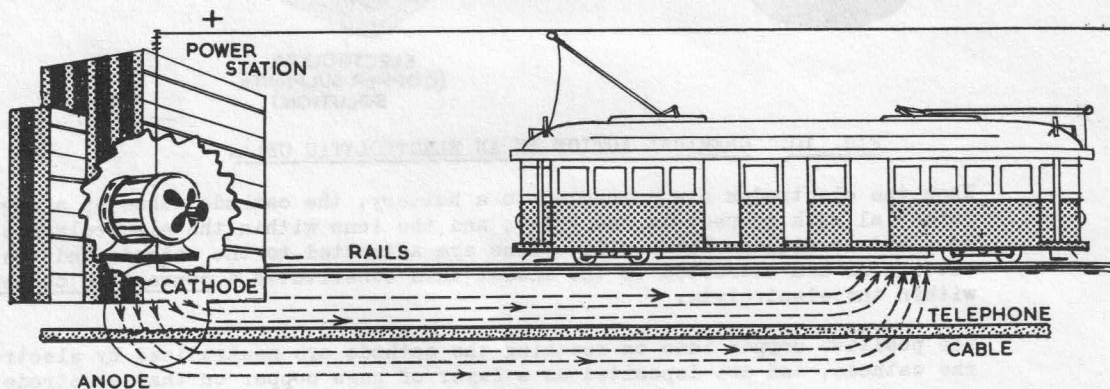
This principle is also widely used in industry for various types of electroplating such as copper, nickel, silver and gold plating.

5. STRAY CURRENT ELECTROLYSIS.

- 5.1 Electrolysis only occurs in D.C. circuits where the necessary factors are present, namely, a cathode or negative element, an anode or positive element, and an electrolyte.

The chemical effect of electrolysis sometimes causes damage to lead covered underground cables. Although this effect in telecommunication is widespread, conditions resulting in electrolysis vary.

Fig. 11 shows how damage is caused by electrolysis due to stray currents from electric tram (or train) lines, passing through nearby cable sheaths, rather than through the earth return, or the rail return of the traction system.



STRAY CURRENTS IN SHEATH OF TELEPHONE CABLES.

FIG. 11.

In this case the rails are the negative element or cathode, the cable sheath is the positive element or anode, and the earth containing salts etc., is the electrolyte.

As in the "electrolytic cell" positive ions are eaten away from the anode to neutralise negative ions in the electrolyte, with the result that the cable sheath becomes corroded and perforated, moisture enters the cable which breaks down due to the failure of the insulation.

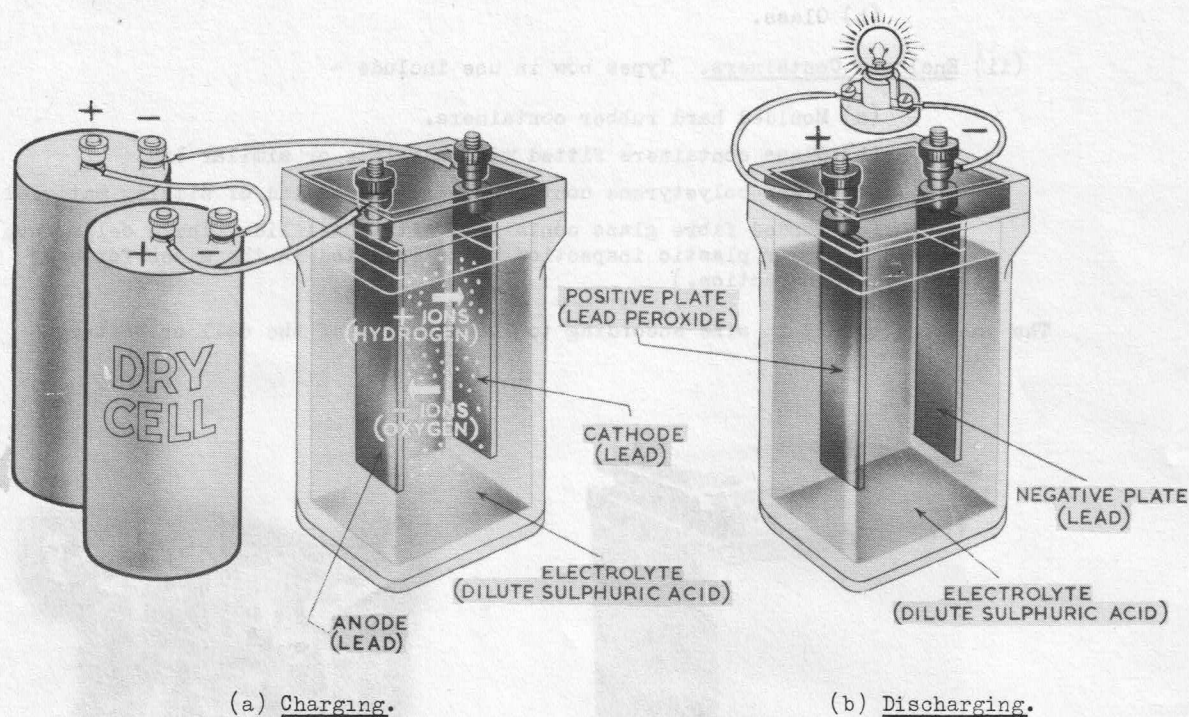
The effects of stray current electrolysis can be prevented in a number of ways; these are described in other books of this Course.

6. LEAD-ACID ACCUMULATOR.

- 6.1 The purpose of most primary cells and batteries is to provide energy for intermittent discharge purposes only, and when the components are depleted the cell is discarded.

Secondary cells, such as the lead acid cell or accumulator, have the characteristic of being able to provide a relatively heavy current over long periods. When the chemical components are depleted, current can be passed through the cell in the reverse direction, and the chemical action of the cell will reverse, restoring the components to their original condition.

- 6.2 Simple Accumulator Cell. When two lead plates are immersed in a dilute solution of sulphuric acid, a trace of lead sulphate is formed on the surface of each plate. When a current is passed through the solution (Fig. 12a) the lead sulphate on the cathode is reduced to metallic lead and on the anode the sulphate is chemically changed to lead peroxide (Fig. 12b).

FIG. 12. SIMPLE ACCUMULATOR CELL.

This cell is in the same category as the electrolytic cells described in paragraph 4.2, for chemical changes have occurred due to the passage of an electric current.

When the cell is disconnected from the voltage source it acts as a voltaic cell exhibiting an e.m.f. of about 2.1 volts, and when connected to an external load will deliver current for a short time until discharged (Fig. 12b).

A reverse current will again restore the components to their original condition, and the cell will again act as a voltaic cell. Continued charging and discharging, (a process called forming), will increase the amount of active material on each plate, but in general the chemical components produced in this way are so small that the cell has only a very small ampere-hour capacity, which makes it impractical for normal use.

In considering the charge-discharge cycle, we should note that on charge, when electrical energy is converted into chemical energy the cell acts as an "electrolytic cell", and on discharge, when chemical energy is converted into electrical energy, the cell acts as a "voltaic cell".

6.3 Make-up of a Typical Accumulator. Most accumulator cells used in telecom are of the lead-acid type. The essential components are a container, positive and negative plates, separators and the electrolyte in which the plates are immersed.

6.4 Containers. Cells are provided with open or enclosed containers, depending upon the purpose for which they are designed (Figs. 13 to 19).

Most modern accumulator cells are now of the enclosed container type.

(i) Open Containers consist of -

- (a) Lead lined wooden containers.
- (b) Glass.

(ii) Enclosed Containers. Types now in use include -

- (a) Moulded hard rubber containers.
- (b) Glass containers fitted with bakelite or similar lid.
- (c) Clear polystyrene containers with fused lid of similar material.
- (d) Bonded fibre glass containers with fused lid. (These cells have clear plastic inspection ports inserted in the sides for easy inspection.)

The containers vary in size according to the capacity of the cell or battery.

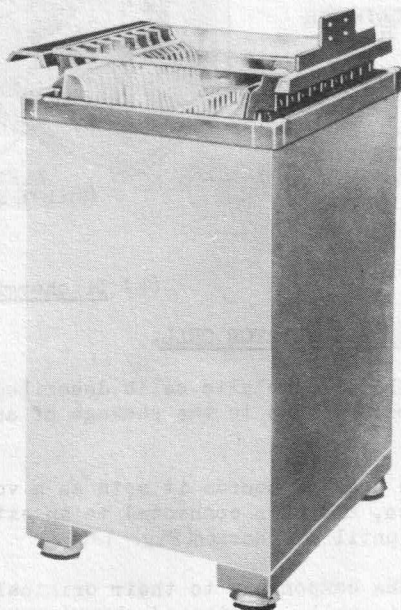


FIG. 13. 2 VOLT OPEN TYPE CELL, LEAD-LINED WOODEN CONTAINER.

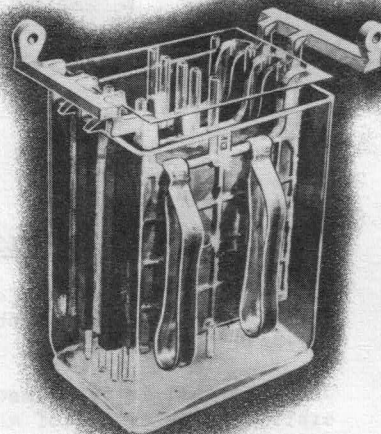


FIG. 14. 2 VOLT OPEN TYPE CELL, GLASS CONTAINER.

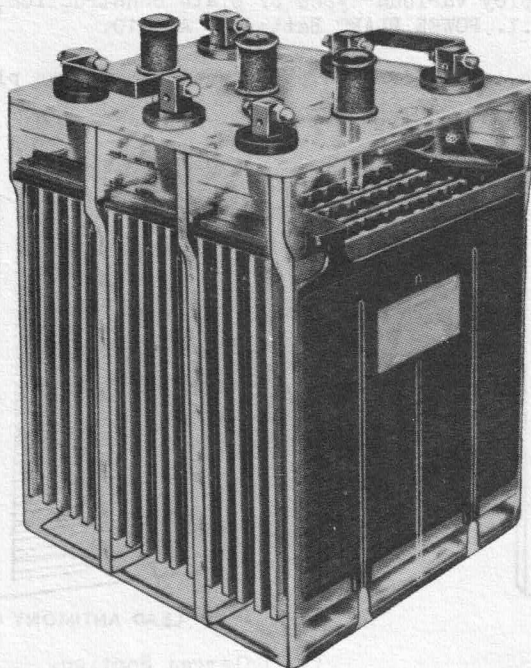


FIG. 15. 6 VOLT ACCUMULATOR ENCLOSED TYPE,
CLEAR PLASTIC CONTAINER.

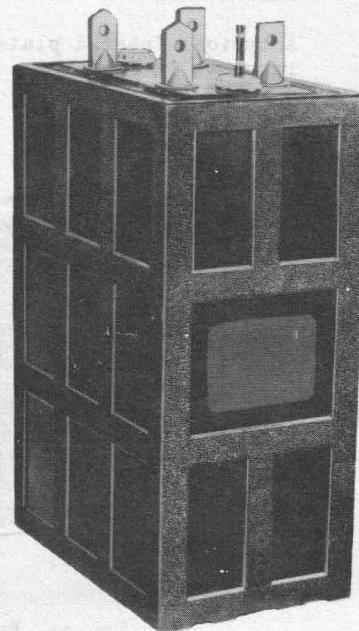


FIG. 17. 2 VOLT CELL ENCLOSED TYPE,
HARD RUBBER CONTAINER.

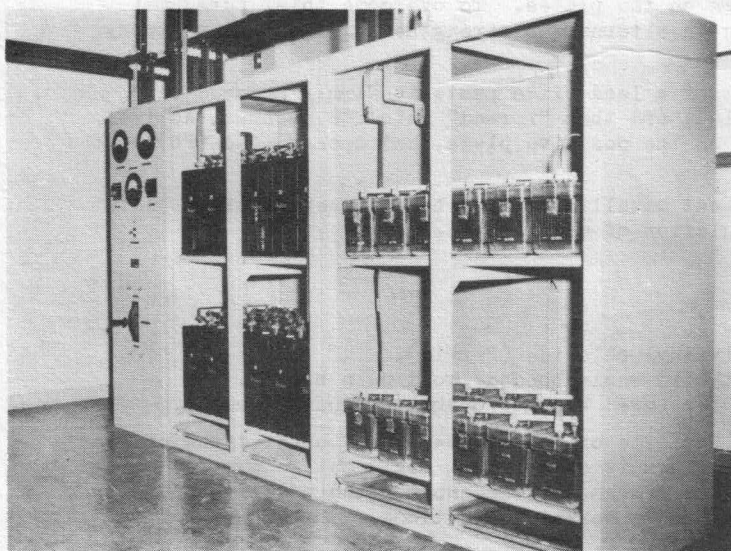


FIG. 16. TYPICAL BATTERY INSTALLATION.

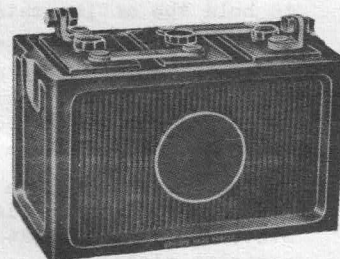


FIG. 18. 6 VOLT ACCUMULATOR ENCLOSED
TYPE, HARD RUBBER CONTAINER.

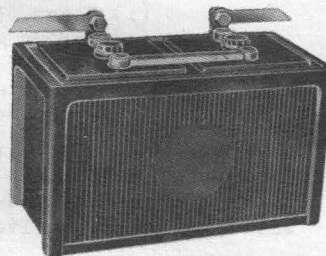


FIG. 19. 4 VOLT ACCUMULATOR ENCLOSED
TYPE, HARD RUBBER CONTAINER.

- 6.5 Plates. The cells used in telecom employ various types of plate construction, full details of which are given in E.I. POWER PLANT Batteries A 2010.

A typical "pasted plate" construction, used for both positive and negative plates, is shown in Fig. 20.

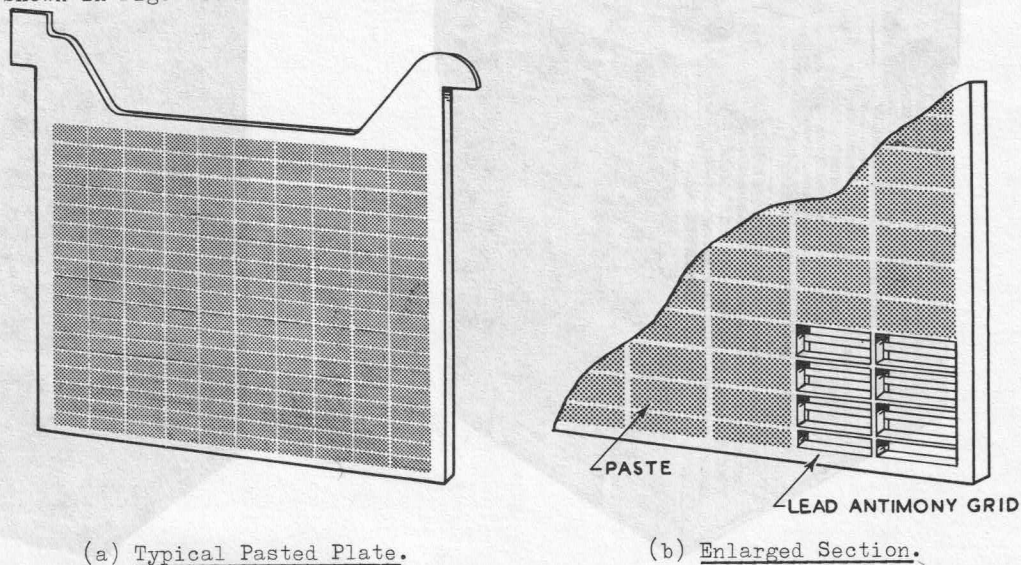


FIG. 20. PASTED PLATE CONSTRUCTION.

Essentially the plates consist of a lead alloy framework or grid, which serves to hold the active material.

The lead is commonly alloyed with antimony to provide a greater framework strength, but it has recently been found that antimony tends to cause local action, and a decomposing action on the plates. To overcome this, pure lead grids and new alloys containing an alternative strengthening agent to antimony (such as calcium), are being used.

The active material in the form of a lead oxide paste is firmly pressed into the spaces of the grids, is dried, and then "formed" into its eventual active state of lead peroxide (PbO_2) on the positive plate, and spongy lead (Pb) on the negative plate.

- 6.6 Separators. The separators prevent metallic contact between neighbouring plates in a cell, but allow free circulation of electrolyte.

Some types of separators are:-

- (i) Glass rods or tubes.
- (ii) Porous wood sheets.
- (iii) Micro porous polyvinyl chloride (Porvic).
- (iv) Resinite (a synthetic-resin bonded, wood pulp board).
- (v) Micro porous rubber (used by some overseas manufacturers).

In conjunction with either the Resinite or the Micro-porous rubber types of separators, a thin mat of fibre-glass is often used. This mat is wrapped around the positive plates, and serves to combat the tendency of the positive plate to shed some of its active material under working conditions.

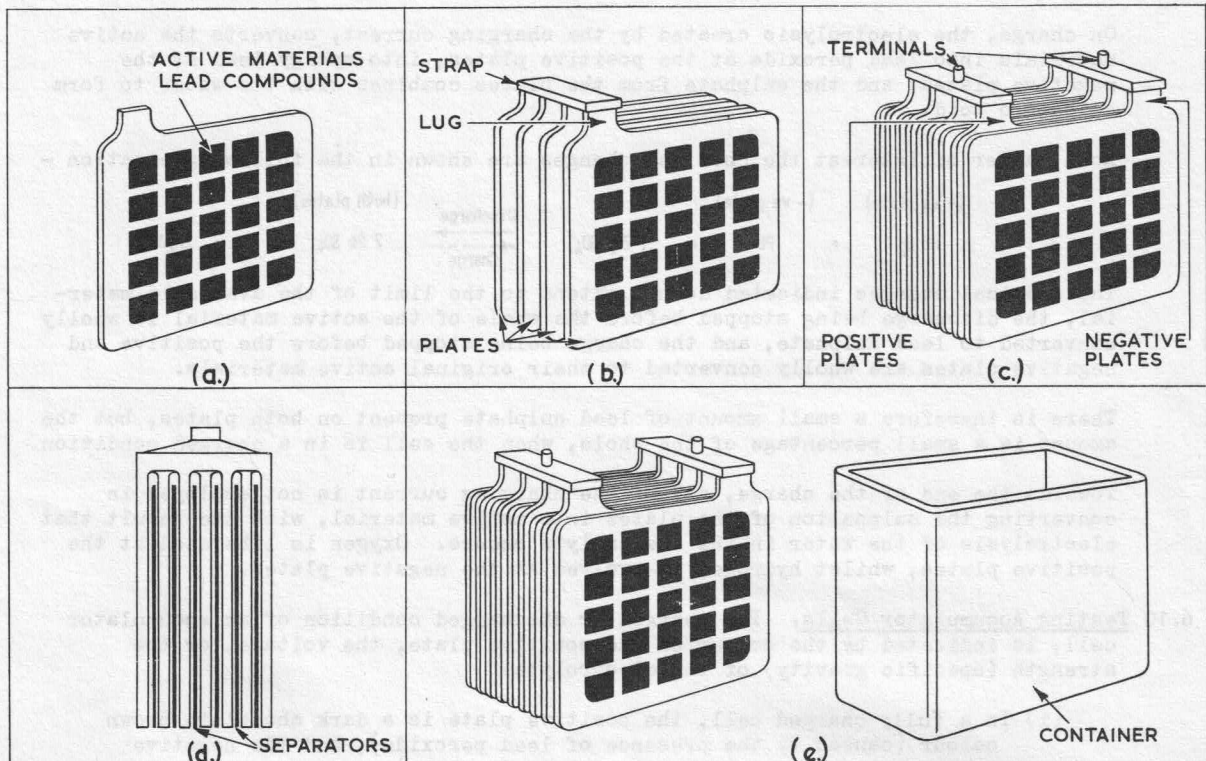
- 6.7 Electrolyte. The electrolyte is chemically pure sulphuric acid of specific gravity 1.840, diluted with distilled water until the specific gravity lies between 1.200 and 1.300, depending on the type of cell.

In general, a fully charged stationary cell has a specific gravity of 1.210 to 1.215, but enclosed type cells have higher values because of the relatively small quantities of electrolyte used.

6.8 Basic Construction. According to the required cell capacity, a selected number of positive and negative plates (Fig. 21a) are connected together in positive and negative groups (Fig. 21b).

The method of connection is by a lead strap which is "lead burned" to the lugs at the top of the plates.

(Lead burning is a form of soldering using pure lead and a heating flame).
Terminals are provided on the lead straps for connection to the external circuit (Fig. 21c).



BASIC CONSTRUCTION OF AN ACCUMULATOR CELL.

FIG. 21.

The negative group usually has one more plate than the positive, so that under working conditions each outside plate is a negative.

In this way the positive plates are worked evenly on both sides, equalising the expansions and contractions of the active material in the positive plates during working conditions, and preventing the buckling of these plates. The negative plates are not subject to this tendency.

The two groups of plates are slipped together (Fig. 21c), and separators are inserted to prevent metallic contacts between the plates (Fig. 21d).

The set of plates and separators is mounted in the container (Fig. 21e) and the electrolyte added.

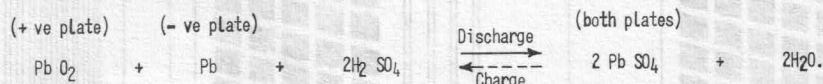
- 6.9 Chemical Action during Discharge and Charge. In the fully charged state, the active material of the positive plate is lead peroxide (Pb O_2), and that of the negative plate is spongy lead (Pb).

On discharge, the sulphuric acid electrolyte combines with the lead in the active material of both positive and negative plates, and lead sulphate (Pb SO_4) is formed on their surfaces.

As discharging continues, the active material in both positive and negative plates continues to be changed into lead sulphate. The electrolyte becomes diluted by the loss of acid during the chemical change, and the formation of water by the combination of the hydrogen (H) and oxygen (O) in the cell.

On charge, the electrolysis created by the charging current, converts the active materials into lead peroxide at the positive plates, into spongy lead at the negative plates, and the sulphate from the plates combines with the water to form sulphuric acid.

As a matter of interest the chemical changes are shown in the following equation -



The chemical changes indicated do not extend to the limit of the available material, the discharge being stopped before the whole of the active material is wholly converted to lead sulphate, and the charge being stopped before the positive and negative plates are wholly converted to their original active materials.

There is therefore a small amount of lead sulphate present on both plates, but the amount is a small percentage of the whole, when the cell is in a charged condition.

Towards the end of the charge, all of the charging current is not employed in converting the sulphation of the plates into active material, with the result that electrolysis of the water in the electrolyte occurs. Oxygen is liberated at the positive plates, whilst hydrogen is evolved at the negative plates.

- 6.10 Testing Accumulator Cells. The charged or discharged condition of an accumulator cell, is indicated by the colour of the positive plate, the voltage, or the strength (specific gravity) of the electrolyte.

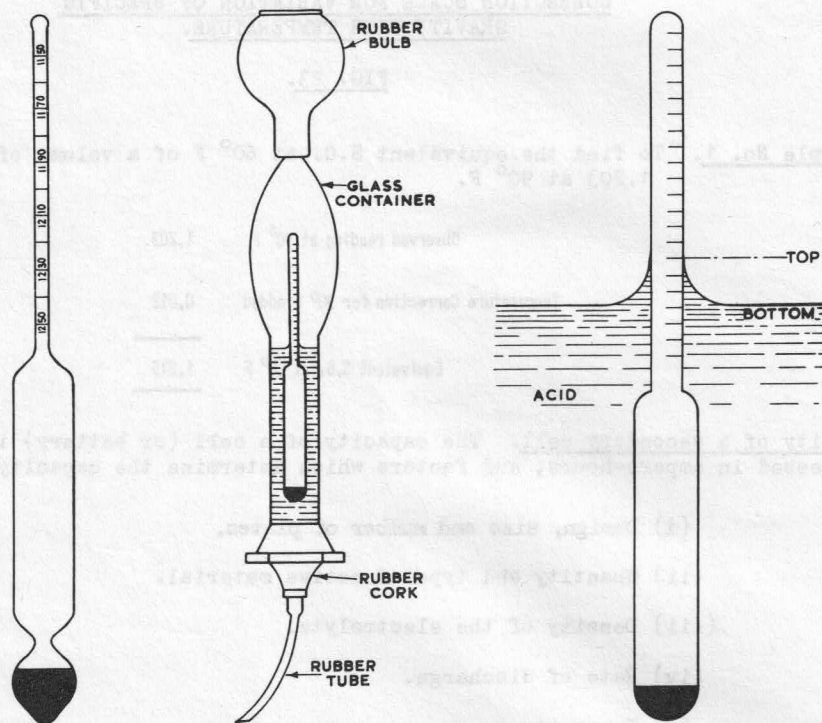
- (i) In a fully charged cell, the positive plate is a dark chocolate brown colour (caused by the presence of lead peroxide), and the negative plate is light grey (the original lead colour).
- (ii) The voltage of a fully charged accumulator cell is about 2.2 volts. This falls rapidly when the cell is first discharged, and normally remains steady at about 2 volts. When the cell is almost completely discharged, the voltage again begins to fall; and at about 1.85 volts, the cell is considered discharged. For calculation purposes, the e.m.f. of an accumulator cell is regarded as 2 volts, irrespective of its size.
- (iii) Specific Gravity is the ratio between the weights of equal volumes of a substance and water. Due to the chemical action, the proportion of sulphuric acid (specific gravity 1.8), to water (specific gravity 1.0) in the electrolyte, and, therefore, the specific gravity of the electrolyte, gradually increases during charge and decreases during discharge. The specific gravity of the electrolyte of a fully charged cell is about 1.215 for open type cells; and about 1.280 for enclosed type cells. When the specific gravity falls to about 1.175, the cell is considered to be discharged and needs charging. For a constant discharge, the specific gravity falls linearly with time.

- ★ 6.11 The hydrometer. There is a direct relationship between the state of charge of the cell and the specific gravity of the electrolyte. In practice, the standard way to test the condition of a cell is to measure the specific gravity of the electrolyte with a hydrometer. Two types commonly used, are -

- (i) The floating hydrometer, (Fig. 22a), used with open type cells. It consists of a glass tube with a calibrated scale and a weighted bulb at the lower end. It is placed in the electrolyte of the cell, and sinks more or less into the solution depending on the specific gravity, which is read directly from the scale.
- (ii) The syringe hydrometer, (Fig. 22b), used with enclosed type cells, and also with open type cells where the separation between plates is small. The hydrometer float is contained in the enlarged portion of a glass cylinder, which has a rubber tube at the bottom and a rubber bulb at the top by means of which acid is sucked in it from the cell under test. After the reading is taken, the acid is re-stored to the cell.

6.12 How to read the hydrometer. To simplify records, and for convenient reference, the specific gravity is multiplied by 1,000 and the hydrometer scales marked accordingly. Thus, when the hydrometer reads 1215, the specific gravity is 1.215.

When taking hydrometer readings, the electrolyte clings to the stem of the hydrometer at the surface. This is called the meniscus. To avoid errors, always read to the bottom of the meniscus (Fig. 22c).



(a) Floating Type.

(b) Syringe Type.

(c) Take readings to the bottom of the meniscus.

HYDROMETERS.

FIG. 22.

6.13 Specific Gravity temperature correction. In conjunction with specific gravity readings, a thermometer is used to record the temperature of the electrolyte, as the specific gravity of the electrolyte has a large temperature coefficient, and all readings must be corrected for temperature.

A temperature increase decreases the specific gravity; a temperature decrease increases the specific gravity.

For temperatures above or below 60° F, a correction factor of 1 point specific gravity variation for each 2.5° F temperature variation, is applied.

When the temperature is above 60° F, the correction is added to the observed reading, and when below 60° F, the correction is subtracted.

Fig. 23 shows a correction scale and Example No. 1 shows how the scale is used.

TEMPERATURE OF ACID IN CELLS (IN °F)	35 40 45 50 55 60 65 70 75 80 85 90 95 100 105
CORRECTION TO OBTAIN EQUIVALENT SP. GR. AT 60°F	<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="text-align: center;"> 10 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 DEDUCT FROM OBSERVED READING </div> <div style="text-align: center;"> ADD TO OBSERVED HYDROMETER READING </div> </div>

CORRECTION SCALE FOR VARIATION OF SPECIFIC
GRAVITY WITH TEMPERATURE.

FIG. 23.

Example No. 1. To find the equivalent S.G. at 60° F of a volume of acid, reading 1.203 at 90° F.

Observed reading at 90° F	1.203
Temperature Correction for 90° F added	0.012
Equivalent S.G. at 60° F	<u>1.215</u>

6.14 Capacity of a secondary cell. The capacity of a cell (or battery) is usually expressed in ampere-hours, and factors which determine the capacity are -

- (i) Design, size and number of plates.
- (ii) Quantity and type of active material.
- (iii) Density of the electrolyte.
- (iv) Rate of discharge.
- (v) Temperature.

6.15 Efficiency of a secondary cell. The ampere-hour efficiency of a secondary cell (or battery), is the ratio of the quantity of electricity available during discharge, to the quantity of electricity required during charge, to restore the components to the fully charged state.

6.16 Internal Resistance of Secondary Cell. The internal resistance of a secondary cell (or battery) varies with -

- (i) size and number of plates,
- (ii) distance between the plates,
- (iii) type of separator,
- (iv) state and rate of discharge of the cell,
- (v) the temperature of the electrolyte.

Cells in good condition, with glass tube separators, and a plate separation of half-an-inch, have a resistance of the following order -

R_b = Internal resistance of battery

$$R_b = \frac{N}{4C} \text{ OHMS}$$

Where N = Number of cells

C = Ah capacity at 10 hour rate

6.17 Precautions Against Explosions in Battery Rooms. Whilst secondary cells are on charge, hydrogen gas is liberated at the negative plate. This gas can form explosive mixtures with air, either in the battery room or within the cell, and if ignited by a flame or spark can cause serious injury to personnel and damage to equipment.

For this reason precautions are taken in battery rooms to prevent these dangerous explosions -

- (i) No naked flames are allowed in battery rooms, for example, smoking and striking matches. Lead burning is permitted only after sufficient ventilation time is allowed for dispersal of the gas.
- (ii) Electric arcs are guarded against, for example, all bolted connections are kept tight and covered with petroleum jelly to prevent corrosion.

Some modern cells are fitted with explosion proof vent caps (Fig. 15) which consist of a porous ceramic cylinder or dome which allows the dispersion of the gas but will not transmit a flame to the interior of the cell.

Cells with these vents often have a funnel through the centre of the cylinder for water additions and hydrometer readings. The outlet of the funnel is below the normal electrolyte level, and the explosive proofing is effective only when the electrolyte covers the outlet.

Full precautions to be observed in battery rooms are listed in E.I. POWER PLANT Batteries SP 1010 "Secondary Cells, Prevention of Explosions."

9. TEST QUESTIONS.

1. An electric cell is a device which changes into
2. State the fundamental difference between primary and secondary cells.
3. The common name for a secondary cell is
4. In a simple voltaic cell an e.m.f. is obtained by placing in an
5. When current flows from a voltaic cell, the visible results are
6. The electron flow in a conductor is termed a conduction current. The movement of within a cell is termed a current.
7. Polarisation within a cell causes a reduction of and
8. Polarisation is caused by
9. To combat the effects of polarisation, a consisting of is used.
10. What is meant by local action, and what is its remedy?
11. Briefly describe the construction and operation of a primary cell.
12. State the method of testing a No. 6 dry cell.
13. When the plates of a lead-acid cell are fully charged the active materials of positive and negative plates respectively are, and
14. The electrolyte of an ordinary lead-acid cell is
15. Briefly describe a lead-acid cell's action on discharge and charge.
16. Modern cells have enclosed type containers manufactured of (i) (ii) or (iii)
17. List four types of separators.
18. Describe the basic construction of a lead-acid accumulator.
19. The state of charge of a cell is indicated by the of the electrolyte.
20. This is measured by a
21. Temperature readings of the electrolyte are also taken. Why is this necessary?
22. The temperature of the electrolyte of a secondary cell is 85° ; what significance has this in the final recording of the cell's state of charge.
23. Why are precautions taken against naked flames in battery rooms?